# Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina

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REGIONAL AQUIFER-SYSTEM ANALYSIS

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of the aquifer system. Farther south, as the amount of micrite in the Ocala decreases, upper Eocene rocks are again included as part of the aquifer system because their permeability is higher.

## SUMMARY AND CONCLUSIONS

The Floridan aquifer system of the Southeastern United States is comprised of a thick sequence of carbonate rocks that are mostly of Paleocene to early Miocene age and that are hydraulically connected in varying degrees. Locally, the aquifer system includes rocks of Late Cretaceous age. In and near its outcrop area, the system consists of a single vertically continuous permeable unit. Downdip, there are generally two major permeable zones (the Upper and Lower Floridan aquifers) separated by a middle confining unit of subregional extent, whose hydraulic properties vary from very leaky to virtually nonleaky. Neither the vertical boundaries of the aquifer system nor its component major high- and low-permeability zones necessarily conform to either formation boundaries or time-stratigraphic breaks. Commonly, the permeability contrast that distinguishes the Floridan aquifer system from its upper and lower confining units occurs somewhere within a rock or time-rock unit.

The subsurface stratigraphy of the coastal plain rocks that comprise the Floridan aquifer system and its contiguous confining units was delineated and mapped on the basis of data from deep test wells of various types. Chronostratigraphic units were chosen for mapping because such units best portray conditions throughout an entire sedimentary basin when complex facies changes such as those found in the eastern Gulf Coast are present. Each chronostratigraphic unit that was delineated includes all or parts of several surface and subsurface formations. The external geometry of each chronostratigraphic unit is shown by structure contour and isopach maps, and internal variations in the units are shown on a series of cross sections that also portray major variations in permeability.

Coastal plain sediments in the eastern Gulf Coast are predominantly clastic from the Fall Line that marks their inland limit. These clastic rocks merge into and interfinger with a thick sequence of platform carbonate rocks that underlies all of peninsular Florida and much of southeastern Georgia. From Paleocene through Oligocene time, the platform carbonate facies successively encroached on the clastic rocks, the result being that progressively younger Tertiary carbonates extend progressively farther to the north and west. The general gentle seaward thickening of coastal plain rocks is interrupted by large- to small-scale geologic structures. Some of these structures, such as Florida's Peninsular arch, the Southeast and Southwest Georgia embayments, and the South Florida basin, have had a major influence on sedimentation and permeability distribution. The Gulf Trough fault system in central Georgia and the Gilbertown-Pickens-Pollard fault zone in southwestern Alabama both strongly influence ground-water flow within the Floridan aquifer system.

Rocks of Cretaceous age underlie the entire study area and generally consist of low-permeability calcareous clay and fine-textured limestone. Updip, sandy Cretaceous rocks form part of the lower confining unit of the Floridan aquifer system except very locally, in the Brunswick, Ga., area, where the upper Cretaceous Lawson Limestone is part of the system.

Paleocene rocks are generally of low permeability throughout the study area except for the permeable dolomite beds in the upper part of the Paleocene Cedar Keys Formation in peninsular Florida, which are included in the Floridan aquifer system. Thick extensive deposits of Paleocene anhydrite in the Florida peninsula form the base of the aquifer system there. Glauconitic Paleocene clastic rocks to the northwest are part of the aquifer system's lower confining unit. The Paleocene-early Eocene boundary is placed in this report at the highest occurrence of either of the planktic Foraminifera *Globorotalia pseudomenardii* Bolli or *G. Velascoensis* (Cushman).

Lower Eocene rocks in the Florida peninsula are part of the Oldsmar Formation, a sequence of limestone and dolomite beds that is in general highly permeable. Like the Paleocene rocks that underlie them, lower Eocene carbonate rocks grade to the north and west into calcareous, glauconitic clastic rocks that are of low permeability. Middle Eocene carbonate rocks in the Florida peninsula have traditionally been divided into the Lake City Limestone below and the Avon Park Limestone above. Well cuttings and core examined during this study show no consistent lithologic or paleontologic difference between the Lake City and Avon Park Limestones. Accordingly, this report proposes that the term Lake City be abandoned and that all middle Eocene carbonate strata in the Florida peninsula and contiguous areas be included in the Avon Park Formation. A reference well section is suggested for the expanded Avon Park Formation. This report further proposes that the term "formation" rather than "limestone" be applied to the Avon Park, Oldsmar, and Cedar Keys units because all commonly contain rock types other than limestone. Middle Eocene rocks show the same westward carbonate-to-clastic transition as lower Eocene and Paleocene strata. This transition occurs farther northward and westward than that of the lower Eocene, which is in turn north and west of the Paleocene clastic-carbonate transition. Most of the low-permeability zones of subregional extent that occur within the Floridan aquifer system are part of the middle Eocene.

Upper Eocene strata consist mostly of carbonate rocks and represent the most widespread transgression of Tertiary seas in the Southeastern United States. Most upper Eocene beds in the study area are part of the highly permeable Ocala Limestone. The Oligocene strata that overlie the Ocala are also in general highly permeable and consist largely of carbonates. Oligocene rocks, however, are relatively thin throughout the study area and have been completely eroded from large areas in northeastern Florida and southeastern Georgia. In most places, either Oligocene or upper Eocene beds mark the top of the Floridan aquifer system.

Lower Miocene sandy limestones mark the end of carbonate bank depositional conditions in the study area. Beginning with the middle Miocene Hawthorn Formation, clastic rocks covered the eastern Gulf Coast almost everywhere. This clastic influx resulted in rapid and complex changes in rock type in the Hawthorn, and the widespread occurrence of Hawthorn phosphorites and high-silica clays show that the waters in the Hawthorn sea were colder than those in older Tertiary oceans. The marginal marine to fluvial origin of most post-Hawthorn rocks in the study area shows that there was a general regression of the sea after middle Miocene time. The upper confining unit of the Floridan aquifer system consists mostly of Hawthorn rocks but includes younger beds in places.

The term Floridan aquifer system is used in this report in place of the older terms "Floridan aquifer" or "principal artesian aquifer." The base of the Floridan aquifer system has been extended downward to include the upper part of the Cedar Keys Formation. The Hawthorn Formation, whose basal limestones have been included as part of the "Floridan aquifer" in older reports, is entirely excluded from the Floridan aquifer system in this report. The Floridan aquifer system generally consists of an Upper and a Lower Floridan aquifer separated by a low-permeability zone (middle confining unit) of subregional extent. In places, no middle confining unit is present, and the aquifer system is permeable throughout its vertical extent. In such places, the entire aquifer system is included in and mapped with its upper major permeable zone, the Upper Floridan aquifer.

Neither the top or base of the aquifer system nor the top or base of the aquifers and middle confining units within it conforms everywhere to the tops of stratigraphic units. Rather, the permeability contrasts that define the aquifer system and its component parts commonly occur within a formation or within a time-stratigraphic unit. Several stratigraphic units or parts of units may mark the top or base of the aquifer system regionally. Likewise, the subregional middle confining units of the aquifer system may consist of different stratigraphic units from place to place.

Hydraulic conditions within the Floridan aquifer system range from unconfined to confined, depending generally on the presence and integrity of low-permeability clastic rocks of Miocene age above the aquifer system. A sandy surficial aquifer is found throughout the study area and may be separated from the Floridan aquifer system by the system's upper confining unit or may be in direct contact with the system where the upper confining unit has been removed by erosion.

Maps of the top, base, and thickness of the Floridan aquifer system, maps of the top and thickness of the Upper and Lower Floridan aquifers, a series of geohydrologic cross sections, and a fence diagram portray the external and internal geometry of the aquifer system. Locally, there are zones of cavernous permeability developed within the aquifer system, and the larger of these cavernous zones are mapped.

The surficial aquifer that forms the uppermost hydrologic unit in the study area generally can be divided into three major parts: (1) the sand-and-gravel aquifer of southwestern Alabama and westernmost panhandle Florida, a thick sequence of fluvial gravelly sand beds; (2) the Biscayne aquifer of southeastern peninsular Florida, a sequence of sandy limestone and sand beds; and (3) a relatively thin but widespread blanket of fluvial to marine terrace sands that covers most of the study area. Water may leak downward from the surficial aquifer to the Floridan aquifer system or be discharged from the Floridan to the surficial aquifer, depending on the vertical hydraulic gradients at any given place.

The upper confining unit of the Floridan aquifer system is a generally thick sequence of clastic rocks and low-permeability carbonates that in places thins to a featheredge and in places is breached by sinkholes and other solution features. The upper confining unit creates the artesian conditions existing throughout most of the area where the Floridan aquifer system occurs. Where the upper confining unit, which consists mostly of rocks of the Hawthorn Formation, is thin or breached, semiconfined conditions exist in the Floridan aquifer system. The regional extent, character, and thickness of the upper confining unit have been mapped for the first time in this report.

Although the Floridan aquifer system is known to extend offshore, it has been mapped only to the coastline in this report. The top of the aquifer system may consist of different ages and types of rocks and its configuration as mapped is determined in part by large- to small-scale geologic features and in part by karst topography developed on the easily dissolved limestone surface. The system's top in most places lies at the top of or within rocks of Oligocene age; where the Oligocene is absent, the system's top is at the top of or within rocks of late Eocene age. Locally, rocks of early Miocene or middle Eocene age comprise the system's top. Some of the small faults that cut the aquifer system's top in places locally limit the extent of the system, as in southwestern Alabama. Other faults, such as those in Florida, have no apparent effect on the system other than to offset its top by a slight amount. A series of small grabens in the central part of the Georgia coastal plain completely cuts the Floridan aquifer system, and movement along the faults that bound these grabens has juxtaposed low-permeability clastic rocks within the grabens opposite permeable limestone to either side and thereby created a damming effect on ground-water flow across the graben system.

The Floridan aquifer system generally thickens seaward from its outcrop area. This general trend is interrupted by several structural features of subregional scale. The Southeast Georgia embayment, the Southwest Georgia embayment, and the South Florida basin represent depocenters within which thick sequences of the carbonate rocks that comprise the Floridan aquifer system were deposited. The system thins over Florida's Peninsular arch. Although the Gulf Coast geosyncline was also a depocenter during Tertiary time, there was a large supply of clastic sediment to the geosyncline, in contrast to the carbonate bank type of depositional system that existed in peninsular Florida and contiguous areas. Accordingly, the Floridan aquifer system is thin around the northeastern rim of the Gulf Coast geosyncline because conditions were not favorable for carbonate deposition.

Within the Floridan aquifer system, there are subregional to local zones of high and low permeability. The uppermost zone of high permeability within the system, called the Upper Floridan aquifer in this report, nearly everywhere yields large volumes of water. The Upper Floridan generally consists of all or parts of rocks of Oligocene age and late Eocene age and the upper half of rocks of middle Eocene age. The thickness of the Upper Floridan as mapped depends partly on structural and depositional conditions and partly on the depth to one of the aquifer system's middle confining units, which form the base of the Upper Floridan.

Seven of the eight subregional low-permeability units that lie within the Floridan aquifer system act as middle confining units separating the Upper and Lower Floridan aquifers. The remaining confining unit lies within the Lower Floridan aquifer. The stratigraphic positions and the rock types of the different units vary greatly. In places, one of the middle confining units may overlie another. In this case, the higher of the overlapping zones is treated as the base of the Upper Floridan aquifer.

Subregional confining unit I, which extends as a coast-parallel band from the Florida Keys to southeastern South Carolina, consists of micritic limestone of middle Eocene age and is the leakiest middle confining unit identified. Subregional confining unit II, which is located in west-central peninsular Florida, consists of gypsiferous middle Eocene dolomite that forms a very low-permeability confining unit. Unit II is overlapped by unit I over a narrow band in central peninsular Florida. Middle confining unit III, located along the central part of the Georgia-Florida border, is gypsiferous, dolomitic middle Eocene limestone that, like unit II, is virtually nonleaky. Unit IV, in the eastern part of the Florida panhandle, is a glauconitic sandstone that extends tonguelike into the lower part of the Floridan aquifer system. Unit IV is of early middle Eocene age and appears to be a leaky confining unit. Middle confining unit V, located in the western Florida panhandle and in southern Alabama, is a massive, dark-colored, virtually nonleaky Oligocene clay. Unit VI, in southwestern peninsular Florida, is a series of low-permeability argillaceous limestone and coarsely crystalline dolomite beds. Unit VI is partly of middle Eocene age and partly of early Eocene age and is overlapped by parts of units I and II. Middle confining unit VII is a narrow strip of gypsiferous limestone of middle to late Eocene age that lies downgradient of and parallel to a small graben system in central Georgia. Restricted flow of ground water across the graben system has been insufficient to dissolve the gypsum from these rocks.

The Lower Floridan aquifer is that series of mostly permeable carbonate beds that lies beneath one of the middle confining units within the Floridan aquifer system. The Lower Floridan's flow system is sluggish, and its hydraulic characteristics are poorly known. In much of southern Florida, a cavernous zone of extremely high permeability occurs within the Lower Floridan aquifer. This interval, called the Boulder Zone, represents a paleokarst horizon that formed in early Eocene rocks. Other cavernous intervals occur in Florida from shallower depths, but they are not found over as wide an area as the Boulder Zone. The Boulder Zone is extensively used along Florida's southeastern coast as a storage zone for liquid wastes (chiefly treated municipal sewage). The Boulder Zone is overlain by a low-permeability micritic limestone that is mapped as middle confining unit VIII. In northeast Florida and southeast Georgia, another deep permeable zone, informally called the Fernandina permeable zone, occurs within the Lower Floridan aquifer in rocks of early Eocene age. The Fernandina permeable zone, which contains saline water, is separated from shallower permeable zones in the Lower Floridan by a micritic limestone confining unit.

The lower confining unit of the Floridan aquifer consists in most places of either massive bedded anhydrite of Paleocene age (part of the Cedar Keys Formation) or glauconitic, calcareous clayey to sandy strata that range in age from late Paleocene to late Eocene. The base of the aquifer system is thus a composite surface that consists of different types and ages of rocks, all of which are of much lower permeability than the rocks of the overlying aquifer system. Some of the larger structural elements of the eastern gulf coast are recognizable on a map of the aquifer system's base. Variations in permeability within the Floridan aquifer system are complex. The porosity and permeability in the carbonate rocks that comprise the system result from a combination of (1) the original texture of the rock, as determined primarily by depositional environment; (2) the diagenetic processes that have acted on the sediment, such as dolomitization and recrystallization, and that are reflected by changes in mineralogy as well as porosity; (3) the joints, fractures, faults, and other structures that affect the integrity of the brittle carbonate rocks and open channels along which ground-water flow can be concentrated; (4) the dissolution of either the carbonate rocks themselves or pore-filling materials such as evaporites and a resulting increase in porosity; and (5) the precipitation of pore-filling minerals, specifically evaporites, either from seawater or from ground water. That most of the major features seen on a map of the potentiometric surface of the Floridan aquifer system can be explained by one of the above factors or a combination thereof demonstrates the effect of the geologic framework of the aquifer system on ground-water flow patterns within it.

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